# TITLE OF THE INVENTION

# WASTE PAPER AND FIBER PROCESSING METHODS AND APPARATUS

## CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. Patent Application No. 09/789,920, filed February 21, 2001 which claims priority of U.S. Provisional Patent Application No. 60/183,858, filed February 22, 2000, incorporated herein by reference.

## STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

N/A

## BACKGROUND OF THE INVENTION

A principal goal in processing waste paper is the recovery of cellulosic fiber pulp with as little damage to the fibers as possible. If such processing damages the paper fibers to a significant degree, product made from the recovered fibers is less strong, has fewer viable commercial uses, and consequently is of a lower economic value to the processor. Processing systems which result in excessively damaged fibers include those which mechanically break baled waste paper apart by use of a device known as a pulper. The bale is preferably soaked in a liquid prior to pulping in order to encourage swelling of the fibers and to result in debonding of the fibers. The soaking step decreases the degree of fiber damage and facilitates the recovery of separated fibers,

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but is inconsistent in effectiveness. Often, waste paper is provided to a recycling facility in large, densely packed bales. To obtain a consistent degree of wetness and consequent swelling and debonding under atmospheric conditions, the soaking cycle must be extended over a relatively long period of time. This leads to a requirement that a facility be capable of maintaining many bales in this soaking state for an extended period. Even given an extended soaking period, fiber swelling and debonding may not be optimal when performed at atmospheric pressure conditions.

One approach which results in an improvement over the prior art involves the soaking of bales under conditions of low pressure or vacuum. To achieve this, a bale of fibrous material to be recycled is loaded into a pressure vessel. Air is removed from the vessel, preferably to at least 25 inches of mercury below atmospheric pressure (-25″ Hg gage), debonding liquid such as caustic liquid is introduced to the vessel while under vacuum conditions, followed by an optional cycle of over-pressure conditions, such as at 100 psig. The vacuum tends to extract much of the air in the bale which otherwise inhibits complete debonding liquid penetration, while the subsequent over-pressure cycle is believed to assist in the penetration of the liquid into the bale. The bale may be maintained at the over-pressure condition for a period of time to enhance the degree of penetration, and/or the over-pressure condition may be removed and the bale may be allowed to remain in the debonding liquid to facilitate swelling. Subsequently,

the treated bale is placed into a traditional pulper though the degree of mechanical pulping necessary is lessened. A certain portion of the bale may be insufficiently swollen, and may require repeated processing as before. The following U.S. Patents are believed to be representative of the just-described processing methods and apparatus, and are incorporated herein by reference: 5,496,439; 5,536,373; 5,271,805; and 5,496,455.

The removal of ink from materials to be recycled is another concern to those involved in the fiber recycling business. Uncontaminated recycled fibers can be used to produce a variety of products including paper having a high degree of whiteness. However, the cost of producing such fibers can offset any financial advantage in having fibers which can be used for high-degree white papers.

One de-inking process is generically referred to as agglomeration, in that the ink is released from the recycled fibers and is bound up, or agglomerated, by the de-inking solution for removal from the pulp slurry through screening. A second de-inking process is referred to as floatation, in which de-inking solution causing the ink to disperse as small particles. Compressed air is introduced into the slurry for agitation and for providing bubbles to which the ink particles cling. The floating ink is then skimmed off. Typically, the de-inking liquid is introduced under atmospheric pressure conditions into a pulp slurry stream which is the product of a pulper as described above. Because such a pulper may produce fibers which are

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incompletely swollen or debound, plural cycles of introducing de-inking chemical, agitating the slurry, removing the freed ink, and recovering the contaminated de-inking chemical must be performed to produce fibers capable of making paper having the desired degree of whiteness. Thus, the prior art process suffers from the need for repeated processing to achieve marginally acceptable results, and requires apparatus specifically configured to enable the recovery of floating or agglomerated ink from the slurry downstream of a pulper.

## BRIEF SUMMARY OF THE INVENTION

The deficiencies associated with the prior art systems and methods described above are addressed by embodiments of the presently disclosed invention. One such embodiment includes an air compressor in communication with a pressure chamber, or autoclave. Once waste paper has been loaded into the autoclave, the compressor pressurizes the chamber, following which caustic swelling and debonding solution is injected into the chamber. The degree of penetration of the caustic into the waste paper is thus improved, process time is reduced, and capital equipment expenditures are reduced. The disclosed high-pressure system may also include the use of an optional vacuum cycle which may be employed to realize an initial over-pressure condition, followed by any combination of under-pressure, ambient or over-pressure conditions.

A further embodiment of the presently disclosed invention employs one of a variety of systems for

providing an initial separation of fibers from either a bale of waste paper or from loose waste paper. The output of the initial separation stage is then introduced into a pulper as known in the art. Subsequent to the operation of the pulper, a slurry of fiber is generated which may not be completely or adequately debonded. The presently disclosed system introduces a caustic solution into the fiber slurry, then subjects the slurry to negative pressure(s) for a period of time chosen to enhance the desired debonding. A thickener container is then employed to densify the resulting fibrous mass.

A third embodiment of the presently disclosed invention addresses the need to remove as much ink and contaminant as possible from recycled fibers while maintaining the integrity of the fibers to the maximum degree possible for use in recycled white paper. The system now disclosed enables the introduction of de-inking chemicals into a pressure vessel or autoclave in which an accumulation or bale of waste paper undergoes defibration through the use of negative pressure followed by optional positive pressure or through the use of positive pressure followed by optional negative pressure. De-inking solution may be introduced subsequent to the introduction and withdrawal of caustic liquid, with or without additional caustic liquid, or with the initial application of caustic liquid. In any permutation thereof, the waste paper is subjected to the de-inking liquid in over- or under-pressure conditions.

It may be possible to fine-tune the parameters of the de-inking process such that subsequent bleaching,

through oxygen, hydrogen peroxide, or any other process, is obviated. Alternatively, bleaching may still be required, though to a less intensive degree. Overall, however, the ultimate advancement is rooted in the introduction of de-inking materials (e.g. agglomeration solution) into the pressure vessel under non-ambient pressure conditions.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The following discussion of advancements in waste paper and fiber recycling technology is presented in conjunction with the attached figures, of which:

Fig. 1 illustrates an apparatus for improved fiber recovery in waste paper recycling;

Fig. 2 is a method of use for the apparatus of Fig. 1;

Fig. 3 illustrates a process and apparatus for improving the degree of fiber recovery provided by a variety of waste paper processing systems; and

Fig. 4 illustrates an improved de-inking process and apparatus therefor.

## DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 illustrates an improved waste paper processing system 10 according to the present disclosure. As contrasted with the prior art specifically cited above, the presently disclosed system includes an air compressor ("air comp.") 12 in communication with a pressure chamber, or autoclave 14. Once the waste paper has been loaded into the autoclave 14, the compressor 12

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charges the autoclave 14 to a value such as one atmosphere over ambient, or in the range of 500 psig. Caustic swelling and debonding solution 16, diluted as necessary with clean or "white" water 18, is then injected into the autoclave 14. A reservoir 20 is provided for storing and mixing the caustic 16 and water 18 prior to introduction into the autoclave 14. The reservoir 20 also provides a receptacle for recycled caustic solution.

The heightened pressure in the chamber 14 enhances the degree of penetration of the caustic 16 into the waste paper, which is preferably and advantageously installed into the autoclave 14 in baled form. By enabling the operation of the disclosed debonding process on baled waste paper, additional, preliminary steps relating to the separation of the waste paper are eliminated, thus providing a savings in terms of time and the cost of the eliminated equipment.

In an alternative embodiment, a high-pressure pump (not illustrated) capable of delivering pressures of at least 150 psi is employed in place of the air compressor 12.

The disclosed high-pressure system 10 may also include the use of an optional vacuum cycle, including separator 22 and vacuum pump 24, to provide further benefits in terms of overcoming resistance to the introduction of caustic liquid into the bale or loose waste paper. If included, the air compressor 12 and vacuum pump 24 may be operated to various degrees to realize processing with an initial over-pressure

condition, followed by any combination of under-pressure, ambient or over-pressure conditions. The actual values for these conditions depend on the components used to realize the system 10, including the autoclave 14 itself. A vent tank 26 is preferably provided in communication with the autoclave 14 and the vacuum pump 24 via the separator 22 for equalizing the autoclave internal pressure with ambient.

A typical process employed by this system 10 is illustrated in Fig. 2. First, waste paper, which is typically mixed office waste (MOW), is loaded into the autoclave 14. As previously suggested, it is preferred to be capable of processing baled waste to avoid excessive damage to the constituent fibers by pre-processing them into a loose form and to simplify the handling of the waste.

Next, the vacuum pump 24 is employed to draw caustic solution (which may be diluted with water as required) from the reservoir 20 to the autoclave 14. In an alternative embodiment, a pump or compressor is employed to perform this function.

The autoclave is then pressurized by the air compressor 12 (or alternatively, the high-pressure pump, depending upon the embodiment). The specific type of waste paper, the density of the bale, the geometry of the autoclave 14, the ambient temperature, and the targeted results of the debonding procedure are all factors to be weighed in defining the pressure to be achieved in the autoclave 14. The desired pressurization is then maintained for an empirically-determined period of time.

Next, the autoclave pressurization is relieved through the vent tank 26, and the vacuum pump 24 is activated in order to draw down the internal autoclave pressure. Once again, a variety of considerations go into the determination of the target degree of vacuum. The vacuum condition is then maintained for a beneficial and empirically-determined period of time.

In one embodiment, the vacuum conditions in the autoclave are relieved, and an over-pressure condition is re-established as described above. The ultimate degree of pressurization and period over which it is maintained may be the same as previous or may differ, depending upon some of the factors listed above.

Following over- and under-pressurization, ambient pressure conditions are re-established in the autoclave 14, and the caustic is drained and/or recycled, as feasible. The autoclave 14 is then unloaded and the resulting mass is pulped according to one of a variety of pulping and/or de-inking processes.

The processing of waste materials including old cardboard containers (OCC) and carrier stock such as six-pack carriers and milk cartons having high wet strength is believed to benefit from the use of over-pressure first processing as enabled by the disclosed system 10. Through the use of this system 10, varying degrees of caustic concentration may be employed such that optimal performance may be achieved at ambient temperature. This is preferred in order to avoid unwanted chemical reactions which typically take place at the elevated temperatures sometimes employed by prior art processing


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systems. Processing time may also be adjusted to optimize swelling and debonding of the fibers to be recycled.

An alternative approach 30 to enhancing the efficacy of a given paper fiber recycling system is illustrated in Fig. 3. Here, one of a variety of systems 32 is employed for providing an initial separation or "cleaning" of fibers from either a bale of waste paper or from loose waste paper. It should be noted that the term "waste paper" is used to include without limitation mixed office waste, paperboard, OCC, and other similar materials, unless otherwise specified. The cleaning process 32 in Fig. 3 can employ one of the negative-pressure processes specifically identified in the patents cited and incorporated by reference in the Background section of this document, the over-pressure system described in conjunction with Figs. 1 and 2 of this document, or some other suitable system.

As a result of the operation of a typical pulper as employed in the cleaning process 32, a slurry of fiber is generated. This is represented in Fig. 3 as the output of the cleaning process 32. Depending upon the fibrous material provided at the start of the process, the state in which it is provided, and/or the type of processing system employed, incomplete swelling and debonding of fibers may result. In some prior art systems, the incompletely separated material must be reintroduced into the start of the cleaning process, thus extending processing time and requiring a significantly larger

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quantity of processing materials (e.g., caustic solution and water).

It is proposed in the presently disclosed system 30 to introduce a caustic solution 34 into the fiber slurry output from the cleaning process 32, then to subject the slurry to negative pressure(s) for a period of time chosen to enhance the desired debonding. A compressor or pump (not shown) may be employed for conveying the caustic into the slurry stream in a manner known to one skilled in the art. This vacuum cycle is employed to enhance the swelling of the fibers in the slurry and to facilitate the saturation of the caustic into the fibers. The source of caustic fluid may optionally include a reservoir 34 with a source of water for diluting the caustic to an optimal degree, similar to that shown in Fig. 1. The degree of dilution may be pre-established, or may vary, depending upon the input to or output from the cleaning or debonding system 32.

Preferably, the disclosed system 30 provides at least two vacuum chambers 36A, 36B in order to provide a continuous system; the two or more vacuum chambers 36A, 36B are operated in reciprocating fashion. In the illustrated embodiment, 150 feet of high-pressure line is utilized for connecting the vacuum chambers 36A, 36B to a blow tank 38, with the slurry moving at five feet per second, for a total processing time of thirty seconds. A vacuum pump (not shown) is employed in a first embodiment for conveying the treated slurry to the blow tank 38 while at negative pressure. Alternatively, a pump or compressor may be employed for the same purpose.


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The blow tank 38 is employed to return the caustic slurry to atmospheric pressure. Next, a thickener container 40 is employed to densify the resulting fibrous mass by allowing the liquid medium to be drained off; caustic recycling is an option. High density (HD) storage 42 is then made available for the extracted fibrous material.

As discussed above, it is highly desirable to remove as much ink and contaminant as possible from recycled fibers, while maintaining the integrity of the fibers to the maximum degree possible, in order to provide fibers suitable for use in recycled white paper. In the prior art, de-inking processes have been carried out in conjunction with the output slurry from, for instance, a pulper. This has been preferred heretofore because prior art recycling processes have been unable to sufficiently wet a substantial portion of the material to be processed with processing liquids prior to pulping. Rather, prior art de-inking systems have been employed only after fibers have been debonded out of baled form and into an extremely low density state in the slurry, such as on the order of one percent fiber. Providing de-inking as a separate process subsequent to pulping requires additional processing equipment, materials such as suspension liquid and chemicals, and time.

To address these disadvantages, the system disclosed in Fig. 4 enables the introduction of de-inking chemicals into a pressure vessel or autoclave in which an accumulation or bale of waste paper undergoes defibration. Prior art systems would not employ de-

inking chemicals during the defibration process because of the need to free the paper fibers through wetting followed by pulping. The presently disclosed system, through the use of negative pressure followed by optional positive pressure, as in the patents cited and incorporated by reference above, or through the use of positive pressure followed by optional negative pressure, as disclosed herein, enables more thorough saturation of the materials to be debonded. Consequently, it is now possible using such systems and methods to introduce de-inking solutions into the pressure processing system. While it may be necessary, using certain pressure profiles and depending upon the materials to be processed, to perform repeated injections and withdrawals of the de-inking solution with or without caustic, this is still preferable in comparison with the provision of a discrete de-inking system which operates subsequent to pulping.

In one embodiment of the presently disclosed system 60, mixed office waste 62 is disposed in an autoclave 64, and debonding is performed through the introduction of caustic solution from a reservoir 66. After draining the caustic to waste (not shown) and/or recycling the caustic to the reservoir 66, a de-inking solution 68 is introduced. While one or more compressors and/or pumps are employed for conveying caustic and de-inking solution into and out of the autoclave 64, the specific details of such systems are considered to be within the purview of one skilled in the relevant art.


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Desirable performance has been achieved through the pressurization of the autoclave 64 immediately following the introduction of the de-inking solution 68. However, a variety of permutations are possible, including the reintroduction of caustic solution 66, albeit at a lower concentration than the initial use, along with the de-inking solution. Similarly, the waste paper to be treated can be exposed to a variety of pressure profiles within the autoclave during the introduction of the de-inking solution 68, including positive pressure, negative pressure, or some combination thereof.

The water wash and ink recovery elements 70 illustrated in Fig. 3 are conventional in a first embodiment. For instance, ink agglomeration may be employed, whereby released and agglomerated ink is skimmed from the surface of the process liquids and disposed of as sludge 72. Alternatively, a proprietary wash and ink recovery system 70 may be employed.

Additionally, the subsequent steps of pulping 74, screening 76, cleaning 78, and optional bleaching 80 may all be as known to one skilled in the art, in one embodiment of the presently disclosed system 60 and method. The treated pulp is then conveyed to storage 82. The physical conveyance of mixed office waste 62, caustic 66, de-inking solution 68, wash water 70, and resulting pulp slurry is achieved through means known to one skilled in the art.

Further, it may be possible to fine-tune the parameters of the de-inking process 60 such that subsequent bleaching 80, through oxygen, hydrogen

peroxide, or any other process, is obviated. Alternatively, bleaching 80 may still be required, though to a less intensive degree. Overall, however, the ultimate advancement is rooted in the introduction of de-inking materials 68 (e.g., agglomeration solution) into the autoclave 64 under non-ambient pressure conditions.

Control over the equipment necessary for realizing the systems as presently disclosed, such as automatic valves, vents, pumps, and compressors, may be achieved through the use of automated controllers, such as a programmed computer, digital signal processor, distributed controller, or other computing device. Sensors utilized by such intelligent controllers in the various embodiments of the presently disclosed concepts, as are familiar to those skilled in the art, include pressure sensors, temperature sensors, level sensors, pH sensors, timers, etc.

A laboratory-sized autoclave system was constructed for purposes of verifying the concepts described above. The system comprised of a cylindrical pressure vessel or autoclave measuring ten inches in diameter and eighteen inches in length, fabricated from 150 psi materials. Also used in this system were: an oil-sealed vacuum pump capable of delivering 27 inches Hg of vacuum; a high-pressure pump capable of delivering pressures up to 150 psi; an air compressor capable of delivering pressures up to 135 psi; and a reservoir tank for storing the treatment liquor until needed for waste processing.

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The lab system was used to perform a variety of tests on mixed office waste (MOW). In general, each test comprised the following steps.

First, the vacuum pump is used to draw treatment liquor into the autoclave, a process which takes roughly 15 seconds.

Second, the autoclave is pressurized ("P1") using the high-pressure pump or compressor for approximately four minutes.

Third, the increased pressure is held for a desired period of time ("H1").

Fourth, vacuum is applied to the autoclave while full of treatment liquor using the vacuum pump ("wet vac").

Fifth, the vacuum is maintained for a desired period of time ("vac hold").

Sixth, the autoclave is pressurized again using the high-pressure pump or compressor ("P2"), a process which takes roughly four minutes.

Seventh, the pressure in the autoclave is held for a desired period of time ("H2").

Eighth, the autoclave is drained using the air compressor to force the treatment liquor back into the reservoir tank.

The parameters for various tests are provided below in Table I, and the results of analyses of the resulting fibers are presented in Tables IIA and IIB. It is worth noting that the components employed in the laboratory test system described above and the test parameters listed below in Table I are not necessarily indicative of


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specifications to be applied to a production system. However, the results of the analyses performed on products of the lab system are believed to provide useful information in determining the optimal characteristics of full-scale treatment processes.

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| Test ID | Test description | Caustic% | Vacuum fill | P1 | Pressure device | H1 | Wet vac | Vac hold | P2 | Pressure device | H2 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Deink 1 | 100% MOW | .15% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec |
| Deink 2 | 100% MOW | .15% | 300mmHg | 110 psi | Air comp. | 30 sec. | 300mmHg | 5 sec. | 110 psi | Air comp. | 30 sec |
| Deink 3 | 100% MOW | .15% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 50mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec |
| Deink 4 | 100% MOW | .15% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 600mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec |
| Deink 5 | 100% MOW untreated | 0 | 0 | 0 | None | 0 | 0 | 0 | 0 | None | 0 |
| Deink 6 | 100% MOW | 0 | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec |
| Deink 7 | 100% MOW | .075% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec. |
| Deink 8 | 100% MOW | .15% in the pulper | 0 | 0 | None | 0 | 0 | 0 | 0 | None | 0 |
| Deink 9 | 100% MOW | .2% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec. |
| Deink 10 | 90% white MOW, 10% green MOW | .15% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec |
| Deink 11 | 50% white MOW, 50% green MOW | .15% | 300mmHg | 110 psi | High pressure pump | 30 sec. | 300mmHg | 5 sec. | 110 psi | High pressure pump | 30 sec. |

TABLE I

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| Analysis | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 |
|---|---|---|---|---|---|---|
| C.S.Freeness, mLs | 381 | 420 | 371 | 358 | 471 | 313 |
| Basis weight, conditioned, g/m2 | 62.42 | 62.92 | 62.48 | 63.51 | 64.32 | 64.54 |
| Bulk, cc/g | 1.65 | 1.73 | 1.59 | 1.64 | 1.76 | 1.54 |
| Burst index, kPa.m2/g | 2.63 | 2.50 | 2.83 | 2.85 | 2.41 | 3.05 |
| Tear index, mN.m2/g | 11.6 | 11.3 | 10.2 | 10.8 | 11.6 | 9.06 |
| Tensile index, N.m/g | 39.8 | 38.3 | 42.6 | 42.2 | 38.1 | 46.9 |
| T.E.A., J/m2 | 53.8 | 49.3 | 56.9 | 60.7 | 47.5 | 69.6 |
| Stretch, % | 3.04 | 2.88 | 3.03 | 3.17 | 2.79 | 3.25 |
| Brightness, on handsheets, % | 78.3 | 75.1 | 78.2 | 82.1 | 82.2 | 75.4 |
| Brightness, TAPPI, recast, % | 75.9 | 73.3 | 75.4 | 80.5 | 81.4 | 74.0 |

TABLE IIA

| Analysis | # 7 | # 8 | # 9 | # 10 | # 11 |
|---|---|---|---|---|---|
| C.S.Freeness, mLs | 352 | 437 | 326 | 333 | 306 |
| Basis weight, conditioned, g/m2 | 64.68 | 63.02 | 62.95 | 63.00 | 64.01 |
| Bulk, cc/g | 1.58 | 1.70 | 1.57 | 1.64 | 1.67 |
| Burst index, kPa.m2/g | 3.18 | 2.36 | 3.11 | 2.83 | 2.56 |
| Tear index, mN.m2/g | 10.2 | 12.0 | 9.37 | 10.1 | 9.30 |
| Tensile index, N.m/g | 48.6 | 38.6 | 48.0 | 42.7 | 39.5 |
| T.E.A., J/m2 | 76.0 | 47.1 | 66.2 | 62.0 | 52.4 |
| Stretch, % | 3.42 | 2.73 | 3.13 | 3.26 | 2.93 |
| Brightness, on handsheets, % | 80.6 | 72.6 | 79.2 | 80.9 | 74.3 |
| Brightness, TAPPI, recast, % | 78.9 | 72.3 | 77.6 | 76.5 | 66.3 |

TABLE IIB

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These and other examples of the inventive concepts illustrated above are intended by way of example and the actual scope of the inventive concepts are to be limited solely by the scope and spirit of the following claims.

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